TITLE: METHOD OF PROVIDING HYDRAULIC/FIBER CONDUITS ADJACENT BOTTOM HOLE ASSEMBLIES FOR MULTI-STEP COMPLETIONS

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CROSS REFERENCE TO RELATED APPLICATION

This nonprovisional U.S. Application claims the benefit of provisional application number 60/174,412, filed on January 5, 2000.

FIELD OF THE INVENTION

The field of this invention comprises methods of allowing the provision of conduits which can carry the power, signal, hydraulic, pressure, fiber optic cable, and other means of communication down to a bottom hole assembly where the completion requires multiple trips.

BACKGROUND OF THE INVENTION

In certain types of completions, a bottom assembly such as, for example, gravel pack screens are assembled as part of the liner and a liner top packer and installed in the well bore. Various operations thereafter occur involving specialized equipment. For example, cementing the liner and gravel packing the screens. After the completion of such steps with specialized equipment, the production string is then tagged into the liner-top packer so that production can begin. Due to the multi-stage nature of such operations, prior techniques for mounting auxiliary conduits to the assembly as it is put together at the surface were not workable. For example, in completions where the liner, liner top packer, and production tubing are inserted in a single trip, the auxiliary conduits

can be assembled to the liner and production tubing as the assembly is being put together at the surface. With these types of single step installations, the auxiliary conduits could be extended to the desired location without the need to disassemble the auxiliary conduits because subsequent trips would be required for different specialized tools.

As previously stated, where the completion requires multiple steps and trips into the well bore, if auxiliary conduits are to be provided to the producing zone, techniques in the past have not been developed to allow that to occur.

More recently a technique has been developed which is subject to a co-pending patent application which is literally repeated as part of this specification, a technique has been developed to allow auxiliary conduits to be sealingly connected to each other down hole. The availability of this development, to solve a different problem, has opened up a possibility of allowing auxiliary conduits to run down to the producing formations adjacent to the bottom hole assembly. The method of this invention is a procedure whereby such auxiliary conduits can be used in conjunction with a variety of down hole operations such as, for example, gravel pack screens. The auxiliary conduits can be used for a variety of purposes such as actuation of down hole flow control devices, chemical injection, actuation of down hole proppant/chemical injection placement valves, distributed temperature data through fiber optic lines, the disposition of discrete sensors whether electric or fiber, pressure measurements, fluid characterization, and flow rate measurements to name a few. The auxiliary conduits can also be used in the gravel packing operation itself. Stated differently, the method of the present invention allows real time feed back of down hole conditions as certain

completion operations are undertaken as well as the ability to sense the formation conditions during production. Accordingly, through the use of fiber optics, one of the objectives of the invention is to sense a variety of data at different times, for example, in a gravel pack completion. The fiber optic cables can be used to sense through pressure impacting them the distribution of the gravel during the gravel packing operation. It can also detect changes in the formation down below during production. Thus, another objective of the invention through the incorporation of the fiber optic technology is to be able to take measurements such as density, impaction, and other physical characteristics of a gravel pack through the use of electrical or fiber optic sensors integrated with screens located in the gravel pack itself. Some of the variables that can be measured with the technique are strain temperature, vibration, pressure, and density to name a few.

Accordingly, it is the objective of the present invention to provide a method whereby auxiliary conduits can be instrumental in the performance of various operations essential to the completion as well as to provide data on a real-time basis of down hole conditions during production particularly in multi-step completion involving multiple trips into the well bore where prior techniques have not allowed auxiliary conduits to extend to the producing zones below a liner top packer, for example.

The following U.S. Patents relate to down hole sensing and also include the use of fiber optics as the sensing devices: 5,925,879; 5,804,713; 5,875,852; 5,892,860; 5,767,411; 5,892,176; 5,723,781; 5,789,662; 5,667,023; 5,579,842; 5,577,559; 5,582,064; 5,570,437; 5,443,119; 5,410,152; 5,386,875; 5,360,066; 5,309,405; 5,252,832; 4,919,201; and 4,783,995.

These patents generally relate to the need to measure parameters in the producing zones of oil, gas, and injection wells. The measurements are used to trace production flow, validate performance of the producing zones, and the equipment installed in those zones, and to optimize production. However, in situations involving multi-trip operations such as a gravel packing a well, such access was unavailable in the previously known devices. In some instances to compensate for this lack of ability to sense in the producing zone, production logging tools or memory logging tools were used. However, running these tools required interruption of production. While these tools provided data, it was only discrete snapshots of the production environment and such information was often provided at a significant direct and indirect cost. Accordingly, one of the objects of the present invention is to provide continuous on demand data to evaluate the performance and health of a well. This is particularly more critical in situations where the completion is complicated as is often used for horizontal and multi-lateral wells.

In the past companies such as Sensor Highway and Pruitt Industries have used control tubes as a means of deploying optical fiber as a distributed temperature sensor, DTS. A pump-down technique has been developed to deploy fiber optic cables in the control tubes. This technique is illustrated in U.S. Patent 5,570,437.

Those skilled in the art will appreciate the scope of the method of the present invention by a description of the preferred embodiment which appears below.

SUMMARY OF THE INVENTION

A technique for providing auxiliary conduits in multi-trip completions is disclosed. The technique has particular applicability to liner mounted screens which are to be gravel packed. In the preferred embodiment, a protective shroud is run with the gravel pack screens with the auxiliary conduits disposed in between. The auxiliary conduits terminate in a quick connection at a liner top packer. The gravel packing equipment can optionally be secured in a flow relationship to the auxiliary conduits so as to control the gravel packing operation. Subsequent to the removal of the specialized equipment, the production tubing can be run with an auxiliary conduit or conduits for connection down hole to the auxiliary conduits coming from the liner top packer for a sealing connection. Thereafter, during production various data on the well can be obtained in real time despite the multiple trips necessary to accomplish completion. The various activities can also be accomplished using the auxiliary conduits such as actuation of down hole flow control devices, chemical injection, pressure measurement, distributed temperature sensing through fiber optics, as well as other down hole parameters.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1a-c are a sectional elevational view of the outer or lower portion of the connector with the running tool inserted therein;

Figures 2a-c show both portions of the connector in sectional elevation connected to each other;

Figures 3a-d show a passage around a packer in sectional elevational view, indicating the path of the control line around the packer sealing and gripping assemblies;

Figure 4 is a schematic elevation view of a well bore having completion and sand control equipment installed therein, said control equipment having the optical fiber system integrated therein;

Figure 5 is an enlarged view of a portion of Figure 4 which illustrates the optic fibers wrapped around the sand control equipment;

Figure 6 is a view of an alternate wrapping pattern of the optic fibers;

Figure 7 is another alternate embodiment of the wrapping pattern of the optic fibers;

Figure 8 is yet another alternate embodiment of the wrapping pattern of the optic fibers;

Figure 9 is a perspective schematic view showing one arrangement for protecting the optic fibers;

Figure 10 is a perspective view showing an alternative arrangement for protecting the optic fibers;

Figure 11 is a perspective view showing another alternate arrangement for protecting the optic fibers;

Figure 12 is a sectional elevational view of the shroud assembly which can be optionally used;

Figure 13 is the sectional elevational view of the screen assembly assembled inside the shroud assembly of Figure 12.

Figure 14 is a sectional elevational view of the combined shroud and screen assemblies installed in a well bore with a liner top packer.

Figure 14a is an elevational view including two sections showing the quick connection between the shroud and tubular.

Figure 15 is an elevational view with one section showing the use of two quick connections to connect a shroud to the tubular and a packer to the tubular on opposed ends.

Figure 16 is an alternative way to secure fiber optic cable to the tubular to measure longitudinal strains in the tubular.

Figure 17 is a perspective view of a well screen with an inlet helix which a fiber optic cable can be inserted so the assembly operates as a two-phase flow meter.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment of the method of the present invention relates to the ability to place auxiliary conduits or/and fiber optics near gravel pack screens. Those skilled in the art will appreciate that other applications for auxiliary conduits adjacent the producing formation are within the scope of this invention. Most applicable are multi-trip completion procedures where there is still a need for real time communication to the surface from the zone where the completion is taking place or where ultimately the production continues, or below.

In the preferred embodiment, a shroud assembly **200** shown in Figure 12 is used. The shroud assembly is a pipe assembled in sections which has perforations **202** and an O- ring seal sub **204** near the lower end. Additionally, a set shoe **206** completes the shroud assembly **200**. A landing nipple

208 is at the top of the shroud assembly **200** and is used for a quick connect to the screen assembly **210** shown in Figure 14a. The detail of this quick connection is a design well known in the art such as is used on lubricators, adapted for this application. In essence, this quick connection allows a ready connection between two tubulars without rotation to facilitate auxiliary conduits disposed on the tubulars. Other modes of fixation of the shroud assembly **200** to the screen assembly **210** can be employed without departing from the spirit of the invention. In fact, the shroud assembly can be completely omitted and is optionally provided to further protect the auxiliary conduits, one of which **212** is shown in Figure 13 disposed between the shroud assembly **200** and the gravel pack screens **214**. Figure 13 also shows a screen polished stinger **216** extending through the O-ring seal sub **204**. The one auxiliary conduit **212** that is illustrated in Figure 13 is indicated to go into a loop around sub **218**. Thus, one or multiple conduits such as **212** can extend down to the O-ring seal sub **204** and can further turn and loop back up through a liner top packer assembly, the bottom of which is illustrated in Figure 15 as **220**. The liner top packer **220** is illustrated systematically in Figure 14.

Those skilled in the art will appreciate that when the shroud assembly **200** is employed, it is assembled and supported from the rotary table. The screen assembly **210** is assembled into the shroud assembly **200** and they are joined at quick coupling **222**, which is a known design. Referring to Figure 14a, the details of the connection between the screen assembly **210** and the shroud assembly **200** are illustrated. The quick coupling **222** allows one or more conduits **212** to pass therethrough. These may be discrete conduits terminating a different end points or a single continuous conduit which loops around or other combinations of the above. Figure 14a illustrates

the landing nipple **208** which accommodates a portion of the quick coupling **222**. The other portion of the quick coupling **222** is secured to the tubular **224**. As seen in Figure 13, the tubular **224** is ultimately connected to the screen or screens **214**. In between the screen assembly **210** and the shroud assembly **200** a ring or rings **226** shown in Figure 14a has a plurality of tabs **228** which help to centralize the screen assembly **210** in the shroud assembly **200**. A plurality of tubes **229** run parallel to the conduits **212**. Tubes **229** are big enough to conduct gravel to different depths to overcome bridging problems. Tubes **229** can have valves in them operated via conduits **212**. Ultimately, when this assembly is put together shown in Figure 13, a wash pipe **230** is inserted through the screens **214** and terminates near the stinger **216** shown in Figure 13. A known gravel packing assembly including a packer **220** (modified to accept the quick coupling **222**) and crossover are inserted and the gravel pack is conducted. Communication to conduits **212** through packer **220** is possible as the gravel packing proceeds. The screen assembly **210** can be assembled to the shroud assembly **200**, preferably at the surface and joined together without relative rotation. The assembled screen assembly **210** and shroud assembly **200** are then run into place with a liner top packer **220** as illustrated in Figure 14. The liner top packer **220** has one or more conduits **212** extending therethrough. These conduits are or can be initially capped off when the packer shown in Figure 14 is run into position. This can be accomplished by a removable bushing **232** shown schematically in Figure 14. The bushing would cap off all conduits **212** which extend through the packer **220**. However, as an alternative to the method of the present invention, the traditional equipment run down with the assembly shown in Figure 14 to accomplish the gravel packing can also have

communication with the conduit or conduits **212** through use of a connector **221** shown in Figs. 1-3. Accordingly, during the gravel packing operation, real time data can be obtained at the surface as to conditions down hole using for example the fiber optic arrays sown i Figs. 4-11. For example, the conduits **212** can include within or outside of them a fiber optic cable which can sense the relative compaction provided by the deposited gravel at different elevations along the screens **214**. It should be noted that the perforations **202** on the shroud assembly **200** are sufficiently large to enable a close pack of gravel around the screens **214** in the area where the conduit or conduits **212** extend. Accordingly, the fiber optic cable can run the length of the screens **214** and give a profile of compaction of gravel per unit length. Additionally, pressure or temperature data can be obtained during the gravel packing operation. Yet another alternative is to control the manner of the deposition of gravel by operating a series of down hole valves in tubes **229** which will deliver gravel at different elevations. Alternatively, the conduits **212** can be made sufficiently large and can terminate at different depths so that valving on each such conduit **212** terminating at a different depth can be actuated by the hydraulic pressure delivered to valving through other conduits **212** so as to open flow paths for gravel deposition, for example. Yet another application is the ability to inject a variety of fluids through one or more conduits **212** in the vicinity of the screen during the completion or gravel packing operation.

Those skilled in the art will appreciate after the packer **220** is set, multiple trips are generally required to finish the gravel packing operation, using standard equipment and known techniques. The individual conduits provided by this invention can be utilized in the same manner on each of

the successive trips or they may be used in differing manners depending on the requirements and equipment utilized during the completion and production phases of the well bore. The method of the present invention, however, allows the opportunity for communication through conduits such as **212** which can include the placement of fiber optics in the vicinity of the screens **214** and the communication of the data to the surface from the vicinity of the screen through signals of conditions sent through the fiber optic network surrounding the screens **214**, in the various embodiments as will be described below in Figures 4 through 11. The ability to ultimately run a production string shown schematically as **234** in Figure 14, along with its set of conduits **236** which match perfectly the conduit or conduits **212** which extend through the packer **220** allows for connection though auxiliary conduits which then extend from the surface to the area of the screens **214**, without the need for rotation. Screens are but one application, other liners such as slotted can also be used or a variety of bottom hole assemblies. In many such applications, the well bores are deviated or horizontal making connection by rotation difficult or impossible. However, using the reconnector **221** as illustrated in more detail in Figures 1 through 3 all the conduits **236** can be sealingly mated to their corresponding conduits **212** which extend through packer **220** without relative rotation. There thus is now a way to allow one or more conduits to extend from the surface to the zone or zones where production will be initiated or resumed or below and, more particularly, in situations where there are multiple trips into the well bore during the completion. Those skilled in the art will appreciate the connection of the auxiliary conduits **236** to their corresponding conduits **212** extending through the

packer **220** can be accomplished on multiple occasions and with different strings and on different trips.

As shown in Figure 15, a known quick connection or coupling such as **222** can be employed also to connect the packer **220** to the tubular **224**. This is shown schematically in Figure 15. The liner top packer **220** can be assembled to the tubular string **224** at the surface or downhole using the quick coupling **222**.

As shown in Figure 15, the quick coupling **222** has uses in multiple applications. The packer **220** can alternatively be attached to the tubular string **224** by other techniques.

The ability to provide one or more conduits down to the producing zone in a completion which requires multiple trips in the well provides numerous benefits. It allows verification and optimization of the performance of a gravel pack completion. It allows a means to continuously monitor the performance of a gravel pack while the reservoir is being produced. The sensors shown schematically as "S" in Figure 13 can be implemented via the conduits **212** to provide data on water breakthrough, fluid flow, and composition as well as equipment performance. The conduits **212** and the ability to control down hole functions or sense down hole conditions can span multiple producing zones and extend below all the producing zones. The technique is particularly applicable for complicated multi-trip completions. As illustrated in Figure 13, the technique provides a way to place temporary and/or permanent sensors in gravel pack zones. The installation technique previously described allows the shroud assembly **200** the screen assembly **210** and the conduits **212** to be run in the well in a single trip. Another advantage is the ability to construct the conduits **212**

and **236** shown in Figure 14 in continuous length without the need for connectors or splices which thus eliminates potential points of failure. The conduits **212** provide a pathway for sensors such as fiber optics, electrical, mechanical, flowable, or chemical, chemical injection and hydraulic fluid control. Additionally, electrical and/or fiber optic connectors can be substituted for the control tubing connection to expand the types of sensors and operations available to the well operator. The bushing **232** is optional and the method of the present invention facilitates the ability to connect and disconnect the auxiliary conduits in a down hole location. Bushing **232** may be removed in a separate trip of with the gravel packing equipment. Standard equipment such as cross overs used for gravel packing can in fact be connected to the liner top packer **220** using the reconnector **221** of Figs. 1-3 to enable real-time monitoring of the gravel packing operation particularly by use of remote or locally operated valving.

Depending on the size of the down hole equipment, five or more isolated conduits such as **212** can be provided. The nature of the down hole equipment can be diverse as discrete sensors or optical fibers can be used in different conduits **212** which obtain different types of data from a variety of locations at the same time and on a real-time basis. The shroud assembly **200** provides protection for the conduits **212** or the exposed fibers such as illustrated in Figs. 4 through 11. Some of the sensors which can be employed can be used to actuate down hole flow control devices. The conduits **212** can be used for chemical injections or actuation of down hole proppant and/or to operate down hole chemical injection valves. The fiber optics can be used for distributed temperature profiles. Additionally, pressure profiles can be obtained or pressure delivered through

the conduit or conduits **212** for operation of down hole equipment or fluid injection. Real-time data can also be obtained that allows for fluid characterization or flow rate measurements. The bushing **232** can act as a debris barrier upon installation of the assembly to the location as shown in Figure 14.

Those skilled in the art will appreciate that the method of the present invention allows sensing of the early arrival of undesired fluid such as water, flash gas, into the log well bores, particularly in the horizontal well bore application. One of the disadvantages of known intelligent well systems and other monitoring systems involves costly on-the-fly joy stick control. However, since accurate monitoring is the overwhelming majority of the information needed for effective well control, the method of the present invention allows knowledge of what the well is doing at any given time and, therefore, allows for other remedial action such as optimized flow rate, altered water injections schemes, and other surface adjustments. Using on-off type methodology as opposed to sophisticated linear control, presents a simpler and more economical solution to the problem particularly in multi-trip completions.

The method of the present invention allows active monitoring of the quality of gravel pack both during gravel packing operations and throughout the life of the oil well. The technique is to measure density, compaction and other physical characteristics of the gravel pack through the use of electrical or fiber optic sensors that are integrated with the screen or located in the gravel pack itself. Typical parameters to be monitored include but are not limited to strain, temperature, vibration, pressure and density. In one embodiment, the optical fibers can be combined with strain

sensors attached to the circumference of the sand control equipment in a configuration or pattern determined by the measurement density desired. Placement of sensors can provide full radius coverage generating a 360° stress profile where desired. The sensors can be installed to measure the changes and stresses of the screen or components of the screen during the gravel packing operation so as to track the progress and quality of the gravel pack. During production, the pressure applied to the screen and/or its outer jacket, if any, will be measured and localized as stress along the length of the circumference of the screen. This provides the operator with information on how the flow into the screen is progressing and also provides information as to the integrity of the well bore. Location and flow rate into the screen or shroud can be characterized both along the length of the tools and circumferentially by virtue of real time monitoring of the applied stresses. The integrity of the well bore can be measured by monitoring the value and location of the stresses applied to the screen or protective shroud due to partial or complete collapse of the well bore cavity. As shown in Figure 16, the optical fiber can be adhered via adhesives to the surface of the structure to be monitored or the fibers may be imbedded within the structure or the fibers can be encapsulated in a carrier coupled to the structure. Figure 16 illustrates the trough into which the fiber is deposited. The optical sensing fiber can be encapsulated in a small metal or plastic or extruded tube that can be wedged or swedged into a mating receptacle groove on the exterior or interior of the structure. This leaves the fiber tightly coupled to the wall of the tube so as to transmit strain from the exterior of the tube into the sensing fiber. In this manner, the sensing element can achieve a high degree of coupling and

allow for automated installation of a very long continuous length of sensing element which spans multiple screens and shrouds if used.

A variation of this method would be to only loosely couple the fiber in the encapsulating tubing so as no external strain is transmitted to the fiber. As the tubing or drill stem is deployed into the well bore, very long lengths of the tubing could be automatically swedged onto the outside of the drill stem or tubing to provide a connector free fiber optic path to downhole devices such as motors, LWD, MWD, and gravel packers. When the drill stem or tubing is retrieved from the well bore, the communication tubing could be automatically removed from the tubing and stored for later reuse.

The optical strain sensor system with or without temperature compensation can incorporate one or multiple optical fibers with discreet sensors, one or multiple optical fibers with more than one optical strain sensor multiplexed into each fiber or one or multiple distributed strain sensors in which the strain of the fiber is measured directly in the fiber.

The electrical embodiment of the system is to substitute and/or combine the electrical sensors and systems for the fiber optic systems in the above embodiments to monitor the completion and operation of the sand control equipment.

In yet another embodiment of the method of the present invention, the fibers can be inserted into helical inlet channels used in conjunction with gravel pack screens to optimize production and delay water or gas coning in long, low-drawdown, high-rate horizontal wells. This product sold by Baker Hughes under the name Equalizer™ has in each segment of gravel pack screen an inlet helix. With fiber optics disposed in such a helix, the ability to sense differing densities in the flowing

stream can be used to determine the composition of the inflowing stream into its separate gas or liquid components. The screen component just described is illustrated in Figure 17 and the disposition of the fiber optic can be in the helix illustrated at the bottom of the figure using techniques of the method described above so as to detect two-phase flow being produced from the formation

The nature of the quick coupling **22** will now be described.

Referring to Figs. 1a-c, the running tool **R** is shown fully inserted into the lower body **L** of the connector **C**. The lower body **L** has a thread **10** at its lower end **12**, which is best seen in Figure 2c. Thread **10** is connected to the bottomhole assembly, which is not shown. This bottomhole assembly can include packers, sliding sleeves, and other types of known equipment.

The running tool **R** is made up of a top sub **14**, which is connected to a sleeve **16** at thread **18**. Sleeve **16** is connected to sleeve **20** at thread **22**. Sleeve **22** is connected to bottom sub **24** at thread **26**. Bottom sub **24** has a bottom passage **28**, as well as a ball seat assembly **30**. The ball seat assembly **30** is held to the bottom sub **24** by shear pin or pins **32**. Although a shear pin or pins **32** are shown, other types of breakable members can be employed without departing from the spirit of the invention. The ball seat assembly **30** has a tapered seat **34** to accept a ball **36** to build pressure in internal passage **38**. Bottom sub **24** also has a lateral port **40** which, in the position shown in Figure 1c, is isolated from the passage **38** by virtue of O-ring seal **42**. Those skilled in the art will appreciate that during run-in, the ball **36** is not present. Accordingly, passage **38** has an exit at the passage **28** so that the bottomhole assembly, which is supported off the lower end of the lower body

L, can be run in the hole while circulation takes place. Eventually, the bottomhole assembly is stabbed into a sump packer (not shown), which seals off the circulation through passage **38**. It is at that time that the ball **36** can be dropped onto seat **34** to close off passage **38**. At that time, O-ring **42** prevents leakage through the port **40**, allowing pressure to be built up in passage **38** above the ball **36**. This pressure can be communicated through a lateral port **44**, as seen in Figure 1a, into orientation sub **46**. Orientation sub **46** has a passage which makes a right-angle turn **48** extending therethrough. Seals **50** and **52** prevent leakage between orientation sub **46** and the running tool **R**.

The running tool **R** also has a groove **54** to accept a dog **56** which is held in place by assembly of retaining cap **58**, as will be described below. When retaining cap **58** is secured to orientation sub **46** at thread **60**, with dog **56** in place in groove **54**, the running tool **R** is locked in position with respect to orientation sub **46**.

Looking further down the running tool **R** as shown in Figure 1b, a seal assembly **62** encounters a seal bore **64** to seal between the lower body **L** and the running tool **R**. A locking ratchet assembly **66**, of a type well-known in the art, is located toward the lower end of the running tool **R**. The ratchet teeth in a known manner allow the running tool **R** to advance within the lower body **L** but prevent removal unless a shear ring **68** is broken when contacted by a snap ring **70** after application of a pick-up force.

The lower body **L** includes a tubular housing **72** which, as previously stated, has a lower end **12** with a thread **10** for connection of the bottomhole assembly. In the preferred embodiment, a pair of control lines, only one of which **74** is shown, run longitudinally along the length of the tubular

housing **72**. The control line **74** terminates at an upper end **76** with a receptacle **78**. In order to make the control line connection, the control line **74** becomes a passage **80** prior to the termination of passage **80** in the receptacle **78**. Passage **80** is shown in alignment with passage **48**. This occurs because when the running tool **R** is made up to the lower body **L**, preferably at the surface, an alignment flat **82** engages a similarly oriented alignment flat **84**. Alignment flat **82** is on the housing **72**, while alignment flat **84** is on communication crossover **86**. The crossover **86** contains a passage **88** which is an extension of passage **48**. Passage **88** terminates in a projection **90**, which is sealed into the receptacle **78** by O-rings **92** and **94**, which are mounted to the projection **90**. Although O-rings **92** and **94** are shown, other sealing structures are within the scope of the invention. In essence, the receptacle **78** has a seal bore to accept the seals **92** and **94**. The orientation of the opposed flats **82** and **84** ensure that the crossover **86** rotates to orient the projection **90** in alignment with receptacle **78** as the crossover **86** is advanced over the running tool **R**. To complete the assembly after proper alignment, the running tool **R** is firmly pushed into the lower body **L** so that the seal **62** engages seal bore **64**, and the locking ratchet assembly **66** fully locks the running tool **R** to the lower body **L**. At this time, the crossover **86**, which is made up over the running tool **R** and is now properly aligned, has its projection **90** progress into the receptacle **78**. Thereafter, the projection **90** is fully advanced into a sealing relationship into the receptacle **78** so that its passage **48** is in alignment with port **44**. This orientation is ensured by alignment of a window **96** in the orientation sub **46** with the groove **54** on the top sub **14** of the running tool **R**. When such an alignment is obtained, the dog **56** is pushed through window **96** so that it partially extends into the window and partially into groove **54**.

At that time, the retaining cap **58** is threaded onto thread **60** to secure the position of the dog **56**, which, in turn, assures the alignment of port **44** with passage **48**. The running tool **R** is now fully secured to the lower body **L** of the connection **C**. Rigid or coiled tubing can now be connected to the running tool **R** at thread **14**.

The bottomhole assembly (not shown), which is supported off the lower end **12** of the body **72**, can now be run into position in the wellbore while circulation continues through passage **38** and outlet **28**. Ultimately, when the bottomhole assembly is stabbed into a sump packer, circulation ceases and a signal is thus given to surface personnel that the bottomhole assembly has landed in the desired position. At that time, the ball **36** is dropped against the seat **34**, and pressure is built up in passage **38** above ball **36**. This pressure communicates laterally through port **44** into passage **48** and, through the sealed connection of the projection **90** in the receptacle **78**, the developed pressure communicates into the control line **74** to the bottomhole assembly. Since, in the preferred embodiment, there are actually a pair of control lines **74**, there are multiple outlets **44** in the running tool **R** such that all the control lines **74** going down to the bottomhole assembly and making a U-turn and coming right back up adjacent the tubular housing **72** and terminating in a similar connection to that shown in Figure 1a, are all pressure-tested simultaneously. If it is determined that there is a loss of pressure integrity in the control line system **74** at this point, the bottomhole assembly can be retrieved using the running tool **R** or alternatively, the running tool **R** can be released from the lower body **L** and the bottomhole assembly can be retrieved in a separate trip. If, on the other hand, the integrity of the control line system **74** is acceptable, pressure can be further built up in passage **38**

to blow the ball **36**, with the ball seat assembly **30**, into the bottom of bottom sub **24** where they are both caught. As a result, the port **40** is exposed so that pressure can be communicated to the bottomhole assembly for operation of its components, such as a packer or a sliding sleeve valve, for example. Once the bottomhole assembly is completely functioned through the pressure applied at port **40**, an upward force is applied to the running tool **R** to break the shear ring **68** so that the entire assembly of the running tool **R**, along with the orientation sub **46** and the crossover **86**, can be removed. As this pick-up force is applied, the projection **90**, which is a component of the crossover **86**, comes out of the receptacle **78** so that each of the control lines **74** (only one being shown) becomes disconnected as the running tool **R** is moved out completely from the lower body **L**.

At this point the upper string **98**, shown in Figure 2a, which is connected to the upper body **U**, can be run in the wellbore for connection to the lower body **L**. Alternatively, the upper string **98** can be inserted at a much later time.

The upper body **U** has some constructional differences from the orientation sub **46** and the crossover **86** used in conjunction with the running tool **R**. Whereas the components **46** and **86** were assembled by hand at the surface, the counterpart components of the upper body **U** must connect automatically to the lower body **L**. Those skilled in the art will be appreciate that the view in Figs. 2a-c is the view of the upper body **U** fully connected into the lower body **L**. However, there are certain components that are in a different position as the upper body **U** approaches the lower body **L**. The string **98** extends as a mandrel to support the upper body **U** and has numerous similarities to the running tool **R** which will not be repeated in great detail at this point. A seal assembly **62**

contacts a seal bore **64**, while a locking mechanism of the ratchet type **66** is employed in upper body assembly **U**, just as in the running tool **R**. Also present is a shear release in the form of an L-shaped ring **68**, which for release is broken by a snap ring **70**. The mandrel **100**, which forms an extension of the upper string **98**, includes an outer groove **102**. During the initial run-in, a series of collet heads **103** is initially in alignment with groove **101**. These collet heads **104** are held securely in groove **102** by sleeve **17** (shown in section in Figure 2c). Sleeve **17** is pushed into this position by spring **126**. The collet heads **104** extend from a series of long fingers **106**, which in turn extend from a ring **108**. Ring **108** is connected at thread **110** to orientation sub **112**. Orientation sub **112** has a passage **114**, including an upper end **116** which one of the accepts the control lines **74** which run from the surface to upper end **116** along the upper string **98**. Again, it should be noted that a plurality of control lines **74** and **74** are contemplated so that when the upper body **U** is connected to the lower body **L**, more than one control line connection is made simultaneously. As previously stated, the control line from the surface **74** extends down to the upper end **116** and then becomes passage **114**. A crossover **86** has a passage **88** which is in alignment with passage **114**. As before, the alignment flat **82** on the tubular housing **72** engages an alignment flat **84** on the crossover **86**. However, rotational movement about the longitudinal axis is still possible while the collet heads **104** are longitudinally captured in groove **102**. This ability to rotate while longitudinally trapped allows the mating flats **82** and **84** to obtain the appropriate alignment so that ultimately, passage **80** can be connected to passage **88** as the projection **90** enters the receptacle **78**, as described above. As this is occurring, the groove **102**, with the collet heads **104** longitudinally trapped to it, comes into alignment with groove **120**, thus

allowing the collet heads **104** to enter groove **120** and subsequently become locked in groove **120** as a result of opposing surface **124**. This is precisely the position shown in Figs. 2a and 2b. Thus, as the connection is firmly made up connecting passage **114** to passage **80** by virtue of a sealed connection between the projection **90** and the receptacle **78**, that position is locked into place as collet heads **104** become trapped against longitudinal movement into groove **120** which is on the tubular housing **72** of the lower body **L**. It is at that time that further longitudinal advancement of the upper string **98** allows the seal **62** to enter the seal bore **64** and ultimately the locking assembly **66** to secure the mandrel **100** to the lower housing **72**. Thus, with seal assembly **62** functional, production can take place through the passage **124** in the mandrel **100**. The seal assembly **62** in effect prevents leakage between the mandrel **100** and the tubular housing **72**, which is a part of the lower body **L**.

When disconnecting, collet **104** drops into groove **102**, and the connection alignment sub **112** and housing **72** start to move apart. To ensure the collet **104** remaining in the groove **102**, sleeve **17** (shown in section in Figure 2c) is pushed over the collet **104** by spring **126**, locking it in place in the groove **102**. The reverse procedure happens when reconnecting.

As shown in Figure 2c, the control line **74** extends beyond the lower end **12** and can extend through a packer as illustrated in Figs. 3a-d. The control line **74** is literally inserted into opening **128** and secured in place with a jam nut (not shown) threaded into threads **130**. The control line **74** extends through a passage **132** and emerges out at lower end **134**, where a jam nut (not shown) is secured to threads **136**. To facilitate manufacturing, the lower end of the passage **132** extends

through a sleeve **138**. The passage through the sleeve **138** is aligned with the main passage **132** and the aligned position is secured by a dog **140**, which is locked in position by a ring **142**. Also shown in Figure 3d in dashed lines is the return control line from the bottomhole assembly going back up to the surface, which passes through the packer shown in Figs. 3a-d in a similar manner and preferably at 180° to the passage **132** which is illustrated in the part sectional view. The control line **74** shown in dashed lines comes back up into the lower body **L** and is connected to the upper body **U** in the manner previously described.

Those skilled in the art will appreciate what has been shown is a simple way to test the control line **74** adjacent to the bottomhole assembly without running the upper string **98** with its attendant control line segments. Once the lower portion of the control line **74** has been tested and determined to be leak-free, the running tool **R** illustrated in Figs. 1a-c can be used to set downhole components. This is accomplished by exposing passage **40** to allow pressure communication to the bottomhole assembly through the running tool **R**. The running tool **R** is simply removed by a pull which breaks the shear ring **68** to allow a pull-out force to remove the running tool **R** from the lower body **L**. Thereafter, the upper body **U**, attached to the lower end of the upper string **98**, is run in the wellbore with the remaining control lines **74**. The connector self-aligns due to the action between the inclined flats **84** and **84**. The orientation sub **112** and the crossover **86** of upper body **U** of the connection **C** are free to rotate within groove **104** to facilitate this self-alignment. The control line segments **74** are made up as a result of this alignment and the male/female connection is sealed, as explained above. More than one control line connection is made up simultaneously. As the

male/female components come together in a sealed relationship, their position is locked as the collet heads **104** become trapped in the groove **120** of the tubular housing **72**. Further advancement of the mandrel **100** relative to the trapped collet hears **104** results in seal **62** engaging the seal bore **64** and locking ratchet mechanism **66**, securing the mandrel **102** to the tubular housing **72**. At this time, the production tubing is sealingly connected as the seal assembly **62** seals between the mandrel **100** and the tubular housing **72**. The control line **74**, one of which is shown in Figs. 2a-c, is connected as the male and female components provide a continuous passage when sealing connected through the boss **144** which contains the passage **80**. Thus, the control line **74** requires a connection at the lower end **146** of the boss **144**. The control line from the surface **74**, as seen in Figure 2a, also has a connection to upper end **116** of orientation sub **112**. Thus, when the male and female components are interconnected as described above, a continuous sealed passage is formed, comprising of passages **114**, **88**, and **80**, which extends from the upper end **116** of orientation sub **112** to the lower end **146** of boss **144**.

Multiple connectors **C** can be used in a given string, and the control lines **74** can have outlets at different locations in the well. One of the advantages of using the connector **C** is that the bottomhole assembly can be run into the well and fully tested along with its associated control lines while the production tubing can be installed at a later time with the remainder of the control line back to the surface. The control line in one application can run from the surface and be connected downhole, as previously described. The control line **74** can continue through a packer through a passage such as **132**. Generally speaking, the control line **74** will have a connection immediately

above the packer. In multiple packer completions, since it is known what the distance between one packer and the next packer downhole is going to be, a predetermined length of control line can extend out the lower end **134** when the packer shown in Figure 3 is sent to the wellsite. The rig personnel simply connect the control line **74** extending out the lower end **134** to the next packer below, and the process is repeated for any one of a number of packers through which the control line **74** must pass as it goes down the wellbore before making a turn to come right back up to the surface. One application of such a technique is to install fiber optic cable through the control line so that the fiber optic cable **F** can extend from the surface to the bottomhole assembly and back up again. Through the use of the fiber optic cable, surface personnel can determine the timing and location of temperature changes which are indicative of production of undesirable fluids. Therefore, on a real-time basis, rig personnel can obtain feedback as to the operation of downhole valves or isolation devices to produce from the most desirable portion of the well and minimize production of undesirable fluids. Fluid pressure can be used to insert or remove the fiber optic cable. There are numerous other possible uses for this technology to be used with other than fiber optic cable without departing from the spirit of the invention.

Those skilled in the art will appreciate that the orientation of the male/female components to connect the control line **74** downhole can be in either orientation so that the male component is upwardly oriented or downwardly oriented without departing from the spirit of the invention. The invention encompasses as connector which can be put together downhole and which is built in a manner so as to allow control line testing, as well as functioning of bottomhole components, without

having run the upper string and its attendant control line. Thus, it is also within the scope of the invention to connect the control line to the upper string in a multitude of different ways as long as the connection can be accomplished downhole and the connection is built to facilitate the testing of the control line adjacent the bottomhole components, as well as the subsequent operation of the necessary bottomhole components, all prior to inserting the upper string. Those skilled in the art will appreciate that the preferred embodiment described above illustrates a push-together technique with an orientation feature for the control line segment of the joint. However, different techniques can be employed to put the two segments of the connector together downhole without departing from the spirit of the invention.

Any number of different pressure-actuated components can be energized from the control line **74**, such as plugs, packers, sliding sleeve valves, safety valves, or the like. The control line, since it runs from the surface down to the bottomhole assembly and back to the surface, can include any number of different instruments or sensors at discrete places, internally or externally along its path or continuously throughout its length, without departing from the spirit of the invention. As an example, the use of fiber optic cable from the surface to the bottomhole assembly and back to the surface is one application of the control line **74** illustrated in the invention. Any number of control lines can be run using the connector **C** of the present invention. Any number of connectors **C** can be employed in a string where different control lines terminate at different depths or extend to different depths in the wellbore before turning around and coming back up to the surface.

Certain applications in the context of gravel pack screens in conjunction with fiber optics will now be described.

Referring to Figure 4, one of ordinary skill in the art will recognize the depiction of a wellbore **11** and installed equipment therein. The equipment includes packers **13** and sand control devices **15** which may be of the added aggregate type or the no-added-aggregate type without affecting the function or components of the invention. Optical fibers **17** are also visible in Figure 4. In order to appreciate the pattern of optical fibers in Figure 4 reference is made to Figure 5 wherein the wrapped fiber **17** is more easily appreciated. The density of the wrapped fiber **17** is dependent upon the spacial resolution of the fiber optic demodulator used in the invention. The equipment at issue is a fiber optic sensing demodulator **19** (Figure 4) which is illustrated at the well head or the surface but which could be placed in an alternate location downhole, may, for example, require one meter of fiber to resolve a condition. in this case, the wrapping pattern must place one meter of the fiber in each area to be monitored. This may require that the fiber be densely wrapped or may allow a less dense wrap depending upon what is monitored. Likewise, a demodulator with higher resolution capacity might need only .25 meters in each location being monitored.

Also visible in Figure 5 is sand control equipment segment **15** joint area **21** where segments of sand control equipment are joined. Preferably in connection with the invention, the fiber **17** may be continuous or optically connected by a connector (not shown) over this joint area **21**. Either method is acceptable and is dictated by circumstances rather than by function. One of ordinary skill in the art is equipped to determine which method is best for this particular application.

Referring now to Figure 6, a very dense fiber optic pattern is illustrated which allows for monitoring of small locations on sand control equipment **15**. The pattern employs both a zig-zag pattern and a longitudinal array of fiber **17**. This may be the same fiber or different fibers. The embodiments of Figs. 7 and 8 also provide varying density of monitoring, varying cost and complexity. Figure 7 provides a longitudinally back and forth pattern of fiber **17** while Figure 8 merely employs Fiber **17** in a conduit **22** at 0 and 180 degrees around the circumference of sand control equipment **15**.

Referring to Figs. 9-11, it is important to note three alternative embodiments to protect the fiber during monitoring. Specifically referring to Figure 9 first, sand control equipment **15** is provided with a groove **25** spiraling along the outside surface thereof. The groove **25** is preferably of dimensions at least slightly larger than the optical fiber to be used so that said fiber will be completely enveloped within the groove and therefore be protected from impact or abrasion during monitoring. In this embodiment the reduction capability of the demodulator to be employed must be known so that the groove **25** is at an appropriate spacing to render the system effective. In another embodiment, referring to Figure 10, a plurality of raised portions (protuberances) **27** are extending from an outer surface of sand control equipment **15**. The arrangement provides additional flexibility since the fiber **17** may be laid around the circumference of the equipment **15** in whatever density it is needed. Many different density levels are possible with the embodiment of Figure 10 while maintaining a protective environment for fiber **17**. A third protective environment for fiber **17** is illustrated in Figure 11. In this embodiment the fiber **17** is actually housed within the sand control

equipment **15** in a conduit **29**. Conduit **29** need only be large enough to house fiber **17** without deforming the same.

In operation, the invention effectively and actively monitors the installation of sand control equipment, its integrity over time and the performance of that equipment. During installation, an exact depth of the sand control equipment is obtainable using a discrete optical signature in the fiber at the location of the downhole equipment and the length of the fiber optic cable that has entered the wellbore. In order to maintain the integrity of the installation and performance thereof, parameters such as chemical species present, vibration, acoustic recognition, pressure, temperature, strain, and density may be queried by the optical demodulator **19** through fiber **17** directly or through integrated sensors. If done directly, monitoring may take place through monitoring point or distributed measurand along the equipment directly through the fiber itself using for example microbending (pressure) Raman Backscatter and optical time domain reflectometry (temperature). Examples of integrated sensor used include interferometry (all parameters) grating, (all parameters) florescence (mostly chemical species, viscosity and temperature) and photoelasticity (temperature, acceleration, vibration and rotational position). From the various measurements, progress and quality of the sand control process can be monitored. The system also provides a real time check on the sand control equipment and will alert surface personnel to problems before damage is done.

It should be noted that the optical fiber **17** can be outside the sand equipment as shown in Figure 9 or inside as shown in Figure 11 or can be in a separate tool (not shown) deliverable to the

sand control equipment through the tubing. In any of these embodiments all of the parameters noted can be sensed and immediate knowledge of the conditions downhole are known at the surface.

Fiber Optic Monitoring of Sand Control Equipment

A method of actively monitoring the installation, integrity, and performance of sand control equipment for the control of unwanted fines that may occur during production, in a well. The instrument is comprised of optical fiber that is integral with, or attached to the inside or outside surfaces of the sand equipment. The optical fiber, or fibers, with or without integrated sensors, will monitor key parameters during the installation process to precisely locate the equipment in the well, monitor all aspects of the installation/completion process, including but not limited to adding aggregate, monitoring of the equipment and then monitoring the integrity and performance of the operational assembly. Typical parameters to be monitored include, but are not limited to chemical species, vibration, acoustic recognition of an event, pressure, temperature, strain, density, and vibration. An embodiment of the instrument is comprised of an optical fiber or fibers attached on the circumference of the sand control equipment in a configuration or pattern determined by the measurement point density desired. The optical fiber attaches to the equipment during the installation into the well. The optical fiber assembly can be comprised of bare optical fiber, or fibers, with or without a variety of coatings and buffers, or optical fiber(s) contained in a cable. The optical fiber assembly can be protected by installing the fiber in channels in the equipment or by the equipment having protuberances to keep the assembly from rubbing the wall of the well. The optical fiber assembly is connected to a fiber optic sensing demodulator either at the surface or at the

wellhead. During installation, the exact depth of the sand control equipment can be determined by monitoring the length of the optical fiber from a known point to a location on the downhole equipment that has a discrete optical signature in the fiber. After the equipment is installed, the optical fiber is used to monitor the process of placement of aggregate material in the production interval(s). Through monitoring point or distributed measurand along the equipment, one method being to measure the pressure and temperature along the length of the equipment due to the aggregate being added, the operator can monitor and record the progress and quality of the process. Pressure measurements can be made using discrete sensors along microbending in the fiber or cable. Temperature along a fiber can be measured using combined Raman Backscatter and OTDR techniques. After the installation is complete and the well is in production, the optical fiber, with or without discrete sensors, can be used to monitor the performance and integrity of the sand control equipment and the production parameters of the well as a whole by monitoring point or distributed measurand.

Several embodiments of the fiber optic monitoring of Sand Control Equipment are possible:

1) The same as above embodiment, but the optical fiber(s), with or without discrete sensors, is built into the equipment. Connections between the equipment segments, can be implemented through connectors, splicing or any other means to communicate the data between equipment segments and the fiber optic sensing demodulator.

2) Install optical fiber in a tube that is integrated with the sand control equipment to monitor temperature along the length of the assembly to assess the aggregate filling process and operational integrity and performance of the system.

3) Along the length of the fiber in Embodiment **1**, integrated acoustic sensors to monitor the acoustic signals associated with filling the equipment with aggregate to monitor the progress and quality of the process.

4) Install fibers the same as the previous embodiments, but use individual or combined measurements of pressure, temperature, acoustic, flow rate, chemical species, fluid density, fluid phase or other measurand to assess the completion process or operational integrity and performance of the installed equipment.

5) Substitute electrical sensors and systems for the fiber optic systems in the above embodiments to monitor the completion and operation of sand equipment.

Fiber Optic Monitoring of Sand Control Equipment via Tubing String

A method of actively monitoring the installation process, integrity and operational performance of sand control equipment, for the control of unwanted fines that may occur during production, with a fiber optic system that is placed in proximity to the equipment. The invention is comprised of optical fiber, with integrated distributed or point sensors, placed in proximity to the sand control equipment. The optical fiber is connected to a fiber optic sensing demodulator, to convert the light signals to measurement parameters, at the wellhead or surface. The optical fiber, or fibers, with or without integrated sensors, will monitor key parameters during the installation

process to precisely locate the equipment in the well, monitor all aspects of the installation/completion process, including but not limited to adding aggregate, of the equipment and then monitoring the integrity and performance of the operational assembly. Typical parameters to be monitored include but are not limited to chemical species, vibration, acoustic emission, pressure, temperature, strain, density, and vibration.

The primary embodiment of the instrument is comprised of an optical fiber or fibers integrated with a tubing string that is installed into a well and located in the area of the sand control equipment. The optical fiber(s) and tubing string can be continuous, or connected in segments to provide length needed to reach the area of interest in the well. During the installation process, the integrity of the optical fiber can be monitored through, but not limited to, optical time domain reflectometry techniques. Once in place, the optical fiber(s) is connected to a fiber optic sensing demodulator either at the surface or at the well head. During installation, the exact depth of the sand control equipment can be determined by monitoring the length of optical fiber from a known point to a location on the downhole equipment that has a discrete optical signature in aggregate material in the production interval(s). Through monitoring point or distributed measurand along the equipment, one method being to measure the change in temperature along the length of the equipment due to the aggregate being added, the operator can monitor and record the progress and quality of the process. Temperature along a fiber can be measured using combined Raman Backscatter and OTDR techniques, as well as other methods. After the installation is complete and the well is in production, the optical fiber, with or without discrete sensors, can be used to monitor

the performance and integrity of the sand control equipment and the production parameters as well as a whole by monitoring point or distributed measurand.

Several embodiments of the fiber optic monitoring of Sand Control Equipment are possible:

1) The same as primary embodiment, but the optical fiber(s), with or without discrete sensors, is located inside a continuous, closed loop, conduit side the tube. The optical fiber can be installed, or replaced, by blowing the optical fiber into the conduit.

2) Integrated acoustic sensors into the optical fiber to monitor the acoustic signals associated with the filling of the equipment with aggregate to monitor the progress and quality of the process.

3) Install a fiber optic sensing system into the tubing to provide individual or combined measurements of pressure, temperature, acoustic, flow rate, chemical species, fluid density, fluid phase or other measurand to assess the completion process, integrity or operational performance of the installed equipment.

4) Use tubing string, or other methods, to dock and undock optical fiber assembly (optical fiber and/or optical fiber cable) to docking point in the well's completion equipment and remove the tubing string. Optical fiber assembly will monitor parameters of interest in the well. The optical fiber assembly can be either retrieved later or left in place for the life of the assembly or well.

5) Substitute and/or combine electrical sensors and systems for the fiber optic systems in the above embodiments to monitor the completion, integrity and operation of sand control equipment.

The foregoing disclosure and description of the invention are illustrative and explanatory thereof, and various changes in the size, shape and materials, as well as in the details of the illustrated construction, may be made without departing from the spirit of the invention.